J Periodontal Implant Sci. 2022 Aug;52(4):261-281
https://doi.org/10.5051/jpis.2007340367
pISSN 2093-2278·eISSN 2093-2286

JPIS Journal of Periodontal & Implant Science

Review
Implant Science

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Survival of surface-modified short versus long implants in complete or partially edentulous patients with a follow-up of 1 year or more: a systematic review and meta-analysis

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OPEN ACCESS

Received: Nov 11, 2020
Revised: Sep 24, 2021
Accepted: Nov 16, 2021
Published online: Feb 17, 2022

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Trial Registration
International Prospective Register of Systematic Reviews (PROSPERO) Identifier: CRD42020160185

Conflict of Interest
No potential conflict of interest relevant to this article was reported.

ABSTRACT

Purpose: Short implants are a potential alternative to long implants for use with bone augmentation in atrophic jaws. This meta-analysis investigated the survival rate and marginal bone level (MBL) of surface-modified short vs. long implants.
Methods: Electronic and manual searches were performed for articles published between January 2010 and June 2021. Twenty-two randomized controlled trials (RCTs) comparing surface-modified short and long implants that reported the survival rate with at least 1 year of follow-up were selected. Two reviewers independently extracted the data, and the risk of bias and quality of evidence were evaluated. A quantitative meta-analysis was performed regarding survival rate and MBL.
Results: The failure rates of surface-modified short and long implants differed significantly (risk ratio, 2.28; 95% confidence interval [CI], 1.46, 3.57; $P<0.000$). Long implants exhibited a higher survival rate than short implants (mean follow-up, 1–10 years). A significant difference was observed in mean MBL (mean difference=−0.43, 95% CI, −0.63, −0.23; $P<0.000$), favoring the short implants. Regarding the impact of surface treatment in short and long implants, for hydrophilic sandblasted acid-etched ($P=0.020$) and titanium oxide fluoride-modified ($P=0.050$) surfaces, the survival rate differed significantly between short and long implants. The MBL differences for novel nanostructured calcium-incorporated, hydrophilic sandblasted acid-etched, and dual acid-etched with nanometer-scale calcium phosphate crystal surfaces ($P=0.050$, $P=0.020$, and $P<0.000$, respectively) differed significantly for short vs. long implants.
Conclusions: Short surface-modified implants are a potential alternative to longer implants in atrophic ridges. Long fluoride-modified and hydrophilic sandblasted acid-etched implants have higher survival rates than short implants. Short implants with novel nanostructured calcium-incorporated titanium surfaces, hydrophilic sandblasted acid-etched surfaces, and dual acid-etched surfaces with nanometer-scale calcium phosphate crystals showed less marginal bone loss than longer implants. Due to high heterogeneity, the MBL results should be interpreted cautiously, and better-designed RCTs should be assessed in the future.

Trial Registration: International Prospective Register of Systematic Reviews (PROSPERO) Identifier: CRD42020160185

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Conceptualization: Raghavendra Shrishail Medikeri, Marisca Austin Pereira; Formal analysis: Raghavendra Shrishail Medikeri, Marisca Austin Pereira, Manjushri Waingade; Investigation: Raghavendra Shrishail Medikeri, Shwetambari Navale, Manjushri Waingade; Methodology: Raghavendra Shrishail Medikeri, Marisca Austin Pereira, Shwetambari Navale; Project administration: Raghavendra Shrishail Medikeri, Manjushri Waingade; Writing - original draft: Raghavendra Shrishail Medikeri, Marisca Austin Pereira; Writing - review & editing: Raghavendra Shrishail Medikeri, Marisca Austin Pereira, Shwetambari Navale, Manjushri Waingade.

Keywords: Dental implants; Marginal bone loss; Short dental implant; Surface treated; Survival

INTRODUCTION

Dental implants are the preferred treatment option for edentulous patients when complicated augmentation procedures, such as vertical/horizontal ridge augmentation or sinus lift surgery, are not involved [1]. However, patients often visit dental clinics with atrophic ridges that require the implantologist to convince the patient to undergo time-consuming, lengthy, and costly augmentation procedures. Short implants are now used as an alternative to augmentation procedures in atrophic jaws. However, short implants have been reported to have lower survival rates due to the crown-to-implant discrepancy, inability to bear the occlusal loads long-term, and reduced bone-to-implant contact [2-7]. Among the various factors that affect implant osseointegration, the surface of the implant is known to have a positive influence [7-8]. Jemat et al. [9] stated that implant surface modification accelerates osseointegration by altering the surface energy and promoting cell proliferation and growth in the local environment. Deporter et al. [10] also reported that implant surface modification played a vital role in the success and survival of short implants. Implant surface modification can be subdivided into additive and subtractive methods [9]. Additive methods include impregnation or coating of the material, while subtractive methods increase the roughness of the surface by removing the material with different blasting substances, grits, and anodization methods [11].

A plethora of information is available on the success rates of short implants relative to long implants. However, very little is known about the influence of implant surface modification on the survival rates of short and long implants. Therefore, the aim of this systematic review was to analyze the survival/success rates of different surface-treated short implants in comparison with similarly treated long implants. The null hypotheses of this meta-analysis are that no differences exist in the survival rates of surface-modified short and long implants and that no differences exist in the marginal bone level (MBL) between surface-modified short and standard implants.

MATERIALS AND METHODS

Search strategy and study selection

This systematic review was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (www.prismastatement.org). The concept of the study was submitted to and assessed by the Center for Reviews and Dissemination's International Prospective Register of Systematic Reviews (PROSPERO) (Reg. No. CRD42020160185).

The research question for this systematic review was presented in the patient, intervention, comparison, and outcome format.

- Patient (P): Partially or completely edentulous patients receiving 1 or more implants in the maxilla and/or mandible.
- Intervention (I): Short implants (≤8 mm) with a modified surface in the partially or completely edentulous maxilla and/or mandible.

- Comparison (C): Long implants (>8 mm) with a modified surface in the partially or completely edentulous maxilla and/or mandible.
- Outcome (O): Effect of surface modification of implants on the survival/failure of short and long implants.

Inclusion criteria

All titles and abstracts of the studies were examined, and relevant studies were selected. Only human, clinical randomized controlled trials (RCTs) with the aim of contrasting surface-modified short with long implants were included. RCTs with at least 1 year of follow-up were chosen to assess the survival and failure rates of short and long implants with modified surfaces.

Exclusion criteria

Animal studies, retrospective or prospective studies, case reports, reviews, non-clinical studies, explanations of techniques, or clinical trials with insufficient information regarding short and long implants were not considered. Studies published in any language other than English were excluded. Studies in which the surface modification of implants was not mentioned were excluded.

Search methods for study identification

An electronic search was conducted to identify studies focused on the clinical performance of surface-modified short and long implants. For that purpose, the PubMed, Cochrane, Clinical Trial Registry, Science Direct, Google Scholar, and Directory of Open Access Journals (DOAJ) databases were searched between January 2010 and June 2021. The search protocol was restricted to the English language. The MeSH terms used in this search were "short implants" OR "short dental implant" AND "long implant" OR "long dental implant" OR "regular implant" OR "conventional implant" AND "surface coated" OR "surface treated" OR "surface modified" AND "success rate" OR "survival rate" OR "failure" AND "marginal bone loss" OR "marginal bone level" OR "periimplant bone loss" OR "periimplant bone level." The following terms were used in an advanced Google search: all of the words "short dental implants" with at least 1 of the words "short dental implants" "long dental implants" "regular implants" "conventional surface modified surface coated." However, no filters were used while searching the Cochrane, Science Direct, Google Scholar, or DOAJ databases.

The titles and abstracts of the searched papers were initially screened by 2 independent reviewers for possible inclusion. Any discrepancies between the reviewers were discussed until a consensus was reached. The summary of study searches is given as a PRISMA flowchart (**Figure 1**).

Data including study design, number of patients, number of implants at baseline, implant length (in mm), number of short implants, number of long implants, implant surface, manufacturing company, location, duration of follow-up, number of failed short and long implants, MBL at follow-up, cumulative implant survival, and success rate were extracted from the included articles. No missing information in the included articles jeopardized the analysis of the selected studies.

https://doi.org/10.5051/jpis.2007340367

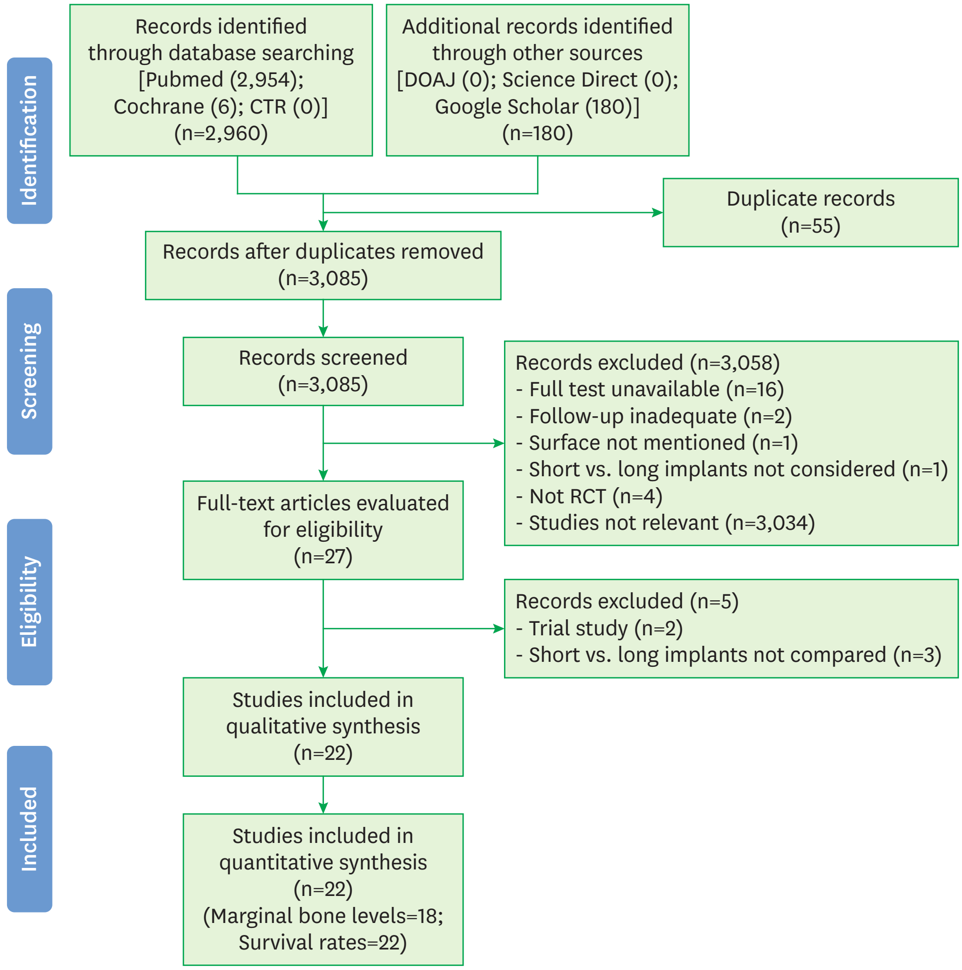

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (2009) flow diagram of the search strategy.
CTR: clinical trial registry, DOAJ: Directory of Open Access Journals, RCT: randomized controlled trial.

Method of analysis

Data collection and analysis

The relevant data from the included publications were collected in data extraction files. Prior to scoring, the rating forms were tested by all reviewers. Each reviewer first determined each study's eligibility for inclusion in the systematic reviews, based on the reported parameters. The data from the included studies were summarized based on clinical and radiographic outcomes in the follow-up period. Two reviewers (RM and MP) evaluated titles, abstracts, and full texts. If opinions diverged, the disagreements among the examiners were re-examined, and decisions were made unanimously or by a third reviewer.

A meta-analysis was performed to evaluate whether significant differences in the survival rate and MBL existed between short and long implants with certain surface modifications. The risk ratios of implant survival rate and mean differences (MDs) in MBL were calculated using a fixed-effect model in which the heterogeneity was shown to be low ($I^2 \leq 50\%$) and a random-effect model in which the heterogeneity was high ($I^2 > 50\%$). All analyses were performed with RevMan Manager 5.3 software (Cochrane, London, UK).

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Quality assessment of the articles

The quality of the selected studies was assessed using the Cochrane collaboration tool (http://ohg.cochrane.org) [11] for RCTs, which accounts for random sequence generation, allocation concealment, blinding of participants, incomplete outcome data, selective reporting, and other sources of bias. The overall risk of bias for randomized trials was determined with the Cochrane Risk of Bias 2.0 tool (Cochrane). The quality of evidence was analyzed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) approach with GRADEpro GDT software (McMaster University and Evidence Prime Inc., Hamilton, Canada) [12].

RESULTS

A systematic electronic search yielded 3,140 references, including 2,954 from PubMed/MEDLINE, 180 from Google Scholar, 6 from the Cochrane Library, and none from the DOAJ and Science Direct databases. After the removal of duplicate references and title and abstract screening, 27 full texts were screened. Twenty-two RCTs [13-34] were included in the final review. Three studies did not compare surface-modified short and surface-modified long implants [35-37], and 2 articles that reported the outcomes of the same RCT at different follow-up times were counted as a single study [38,39].

Risk of bias and quality of evidence

The Risk of Bias 2.0 tool indicated that all of the studies showed a low risk of bias considering random sequence generation, allocation concealment (selection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias), and other sources of bias, except 4 studies with high risk of bias [19,22,26] due to lack of data on randomization and blinding [26,30], missing outcome data [15], and selective reporting [14]. One study was underpowered because the data available for analysis after drop-out were not sufficient [19] (**Figure 2**).

According to the GRADE system, the pool of studies on implant survival rate and MBL constituted high-quality evidence (**Supplementary Tables 1** and **2**). However, the wide confidence intervals (CIs) and high risk of bias in a small number of studies should also be considered, and the results should be interpreted with caution.

Descriptions of the studies

The 22 studies are summarized in **Table 1** [13-34]. All studies compared the survival rates and MBLs of surface-modified/surface-treated short vs. long implants. Certain studies provided data in the form of differences in marginal bone loss at baseline and follow-up, but such data were not used in the present meta-analysis to assess MBL. Seven studies were analyzed regarding the survival rates of short vs. long fluoride-modified implants [14,19,23,28,29,33,34]; however, only 5 studies could be evaluated regarding MBL [14,23,28,33,34]. Three studies used conventional sandblasted acid-etched surface implants [15,27,30], and 5 studies evaluated the survival rates and MBL of implants with nanostructured calcium phosphate-modified surfaces [13,17,20,25,31]. Five studies assessed the survival rates of hydrophilic sandblasted acid-etched implants (209 short vs. 218 long) [18,21,22,26,32]; however, only 3 studies evaluated the MBL [18,21,22]. Felice et al. [16,24] examined dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals (with 90 short and 91 long implants), and these 2 studies were included in the meta-analysis regarding survival rate and MBL.

https://doi.org/10.5051/jpis.2007340367

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Studies	Randomization	Deviations from intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall risk of bias
Pistilli et al. (2013) [13]	+	+	+	+	+	+
Guljé et al. (2013) [14]	+	+	+	+	+	+
Esposito et al. (2014) [17]	+	+	+	+	+	+
Felice et al. (2014) [16]	+	+	+	+	+	+
Romeo et al. (2014) [15]	+	?	+	+	+	+
Schincaglia et al. (2015) [19]	+	+	−	+	+	−
Rossi et al. (2015) [43]	+	+	+	+	+	+
Bechara et al. (2015)	+	+	+	+	+	+
Sahrmann (2016) [22]	+	+	+	+	+	+
Nedir et al. (2016)	+	+	+	−	+	−
Pohl et al. (2017) [23]	+	?	+	+	+	+
Zadeh et al. (2018) [29]	+	+	+	+	+	+
Thoma et al. (2018) [28]	+	+	+	+	+	+
Storelli et al. (2018) [27]	+	+	+	+	+	+
Felice et al. (2018) [24]	+	+	+	+	+	+
Gastaldi et al. (2018) [25]	+	+	+	+	+	+
Shah et al. (2018) [30]	?	+	+	+	+	+
Naenni et al. (2018) [26]	?	+ (red)	+	+	?	−
Felice et al. (2019) [31]	+	+	+	+	+	+
Shi et al. (2019) [32]	+	+	+	+	+	+
Guida et al. (2020) [33]	+	+	+	+	+	+
Hadzik et al. (2021) [34]	+	+	+	−	+	−

+ Low risk
? Moderate risk
− High risk

Figure 2. Risk of bias of included studies. Green: low risk, yellow: moderate risk, red: high risk.

In 1,472 patients, a total of 1,100 surface-modified short and 1,118 surface-modified long implants were evaluated. At the end of the follow-up period, 1,045 short implants and 1,094 long implants had survived (**Table 2**). **Table 3** summarizes the details of each type of implant surface studied, including the corresponding survival rates. The mean follow-up period was 3.52±2.24 years (range, 1–10 years).

Implant survival rate

Twenty-two studies [13-34] showed that 55 of 1,100 short implants and 24 of 1,118 long implants failed (**Table 1**). The RR for overall survival rate between the 2 groups was 2.28 and was statistically significant ($Z=3.61$; $P=0.0003$; 95% CI, 1.46, 3.57) (**Table 4** and **Figure 3**). Surface-modified short implants showed higher failure rates than long implants. The influence of surface modification on the implants of different length was further evaluated. Only the hydrophilic sandblasted acid-etched and fluoride-modified titanium oxide surfaces showed statistically significant differences in the survival rates of short vs. long implants ($P=0.02$; RR=3; 95% CI, 1.2, 7.48 and $P=0.05$; RR=3.54; 95% CI, 1.00, 12.52, respectively) (**Figures 4** and **5**). This indicates that hydrophilic sandblasted acid-etched and titanium

https://doi.org/10.5051/jpis.2007340367

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Table 1. Characteristics of all included studies

Author & Year	Study design	No. of patient	No. of implants	No. of short implants	No. of long implants	Location	Implant surface	Additional information	Manufacturer	Smokers	Follow-up period (yr)	No. of patients lost to follow-up	No. of short implant failed	No. of long implants failed	Survival rate (%)		MBL	
															Short implants[a)]	Long implants[a)]	Short implants[a)]	Long implants[a)]
Pistilli et al. (2013) [13]	RCT	80	80	40	40	Maxilla=40 Mandible=40	Novel nanostructured calcium incorporated titanium surface	-	MegaGen Implant	7	1	2	1	2	97.5	95	1.18 (0.29)	1.36 (0.28)
Guljé et al. (2013) [14]	RCT	95	208	107	101	Maxilla=35 implants Mandible=61 implants	Fluoride treated nanostructured surfaces	4 mm diameter	OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants	8	1	1	3	1	97.19	99	0.2 (0.22)	0.41 (0.46)
Romeo et al. (2014) [15]	RCT	24	54	26	28	Maxilla=12 implants Mandible=40 implants	SLA surface	-	Staumann Implant System	8	5	5	1	0	90	100	2.97 (0.47)	2.99 (0.9)
Felice et al. (2014) [16]	RCT	60	121	60	61	Mandible	Nanotite (dual-acid-etched surface coated with nanometer scale crystals of calcium phosphate)	-	BioMet 3i	23	5	8	5	3	91.66	96.72	2.24 (0.47)	3.01 (0.74)
Esposito et al. (2014) [17]	RCT	30	128	60	68	Maxilla n=15 (72 implants) Mandible n=15 (56 implants)	Novel nanostructured calcium incorporated titanium surface	-	MegaGen Implant	6	3	6	5	2	91.66	97	1.57 (0.55)	1.87 (0.50)
Rossi et al. (2016) [18]	RCT	45	60	30	30	Maxilla n=27 Mandible n=33	SlActive	4.1 mm diameter	Straumann AG, Waldenburg, Switzerland	Test group=6 Control group=7	5	-	4	1	86.7	96.7	2.30 (0.52)	2.64 (0.56)
Schincaglia et al. (2015) [19]	RCT	97	122	61	61	Maxilla	Fluoride treated nanostructured surfaces	Transmucosal implants	OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants	Test group: NS=32, FS=10, S=8 Control group: NS=23, FS=15, S=13	1	3	0	0	100	100	−0.22 (0.4)	−0.3 (0.45)
Bechara et al. (2017) [20]	RCT	33	90	45	45	Maxilla	Novel nanostructured calcium-incorporated surface	-	MegaGen Implant	15	3	0	0	2	100	95.6	0.27 (0.08)	0.20 (0.07)
Nedir et al. (2017) [21]	RCT	12	37	17	20	Maxilla	SLActive	Transmucosal healing	Institut Straumann AG	-	5	-	1	2	94.1	90.0	0.6 (0.9)	0.7 (1.4)
Sahrmann (2016) [22]	RCT	96	94	47	47	Maxilla=42 Mandible=56	SLActive	Transmucosal healing	Straumann AG, Waldenburg, Switzerland	23	3	16	1	0	98	100	0.19 (0.62)	0.33 (0.71)

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https://doi.org/10.5051/jpis.2007340367

Table 1. (Continued) Characteristics of all included studies

Author & Year	Study design	No. of patient	No. of implants	No. of short implants	No. of long implants	Location	Implant surface	Additional information	Manufacturer	Smokers	Follow-up period (yr)	No. of patients lost to follow-up	No. of short implant failed	No. of long implants failed	Survival rate (%)		MBL	
															Short implants[a)]	Long implants[a)]	Short implants[a)]	Long implants[a)]
Pohl et al. (2017) [23]	RCT	101	104	52	52	Maxilla	Fluoride treated nanostructured surfaces	Transmucosal healing	OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants	-	3	Short=2 (2 implants) Long=1 (1 implant)	0	0	100	100	0.45 (0.55)	0.45 (0.55)
Felice et al. (2018) [24]	RCT	66	60	30	30	Mandible	Nanotite (dual-acid-etched surface coated with nanometer scale crystals of calcium phosphate)	-	Biomet 3i	Test group=12 Control group=1	8	12	5	3	83.33	90	2.34 (0.53)	3.13 (0.76)
Gastaldi et al. (2018) [25]	RCT	80	80	40	40	Maxilla n=40 Mandible n=40	Nanostructured calcium-incorporated (5×5 mm)	Platform switching 4.0 mm diameter	MegaGen	Test group=7 Control patents=6	3	7	2	2	95	95	1.33 (0.38)	1.7 (0.36)
Naenni et al. (2018) [26]	RCT	86	86	40	46	Maxilla=12 (short); 22 (long) Mandible=28 (short); 24 (long)	SLActive	All implants were placed according to a nonsubmerged 1-stage surgical protocol	Institute Straumann AG	21 patents	5	8	4	0	91	100	−0.29 mm (IQR, −0.92, 0.23)	−0.15 mm (IQR, −0.93, −0.41)
Storelli et al. (2018) [27]	RCT	17	40	20	20	Mandible=30 Maxilla=10	SLA	Diameter=4.1 mm Machined transmucosal neck=2.8mm	Straumann AG, Basel, Switzerland	-	10	8	1	0	95	100	3.26 (0.77)	3.14 (0.94)
Thoma et al. (2018) [28]	RCT	90	137	67	70	Maxilla	Fluoride treated nanostructured surfaces	-	OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants	46 patents	5	5	1	0	99	100	0.45 (0.79)	0.45 (0.91)
Zadeh et al. (2018) [29]	RCT	95	209	108 4.0×6 mm	101 4.0×11 mm	Maxilla=104 implants Mandible=105 implants	Fluoride treated nanostructured surfaces	Platform switched Internal conical connection Microthreads	OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants	8 ex-smoker=26	3	5	4	1	96	99	Mean bone gain=0.04 (0.43)	Mean bone loss=0.02 (0.76)
Shah et al. (2018) [30]	RCT	50	50	25	25	Maxilla=23 Mandible=27	Conventional sandblasted and acid etched surface	Non-submerged with customised healing abutmet	MIS even	11 former smokers 2 or 3 current smokers	1	7:5 short and 2 long implants	4	1	84	96	-	-

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https://doi.org/10.5051/jpis.2007340367

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Table 1. (Continued) Characteristics of all included studies

Author & Year	Study design	No. of patient	No. of implants	No. of short implants	No. of long implants	Location	Implant surface	Additional information	Manufacturer	Smokers	Follow-up period (yr)	No. of patients lost to follow-up	No. of short implant failed	No. of long implants failed	Survival rate (%)		MBL	
															Short implants[a)]	Long implants[a)]	Short implants[a)]	Long implants[a)]
Felice et al. (2019) [31]	RCT	30	128	60	68	Maxilla=15 (72 implants) Mandible=15 (56 implants)	Nanostructured calcium-incorporated	-	MegaGen	6 patents	5	6	5	2	91.66	97	1.83 (0.65)	2.24 (0.63)
Shi et al. (2019) [32]	RCT	225	150	75	75	Maxilla	Straumann standard plus implants (SLActive)	-	Institute Straumann AG, Basel, Switzerland	-	1	8	Group 1=1 Group 2=5	2	Group 1=96 Group 2=100	Group 3=100	Group 1=0.51±0.23 Group 2=0.47±0.43	0.52±0.26
Guida et al. (2020) [33]	RCT	30	150	75	75	Mandible	Fluoride treated nanostructured surfaces	-	OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants	4	3	-	0	0	100	100	0.36 (0.35)	0.25 (0.19)
Hadzik et al. (2021) [34]	RCT	30	30	15	15	Maxilla	Fluoride treated nanostructured surfaces	-	OsseoSpeed TX, Astra Tech Implant System, Dentsply Sirona Implants	Excluded	7	-	2	0	87	100	0.22 (0.46)	0.34 (0.24)

RCT: randomized control trial, IQR: interquartile range, NS: non-smoker, FS: frequent smoker, S: smokers, OsseoSpeed: fluoride treated nanostructured surfaces, -: not mentioned.
a)Data at the follow-up period.

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Table 2. Summary of survival rates of short and long implants

Total No. of RCT	Total No. of patients	Total No. of implants	Total No. of short implants (survived implants)	Total No. of long implant (survived implants)	Total No. of failed short implants	Total No. of failed long implants
22	1,472	2,218	1,100 (1,045)	1,118 (1,094)	55	24

RCT: randomized control trial.

Table 3. Summary of data of implant surfaces

Implant surface	No. of studies	Total No. of implants	No. of short implants	No. of long implants	Total No. of failed short implants	Total No. of failed long implants	Survival rate (%)	
							Short implants	Long implants
Hydrophilic sandblasted acid-etched [18,21,22,26,32]	5	427	209	218	16	5	92.3	97.8
Conventional sandblasted acid-etched [15,27,30]	3	144	245	73	13	10	91.5	98.6
Titanium modified fluoride treated nanostructured surfaces [14,19,23,28,29,33,34]	7	960	485	475	10	2	98	99.57
Novel nanostructured calcium-incorporated surface [13,17,20,25,31]	5	506	245	261	13	10	95	96.16
Dual acid-etched surface coated with nanometer scale crystals of calcium phosphate [24,31]	2	181	90	91	10	5	88.88	94.5

Table 4. Summary of meta-analyses comparing survival rate of different surface modified short vs. conventional implants

Implant surface	Studies	Pooled RR (95% CI)	*P* value	I^2 value (%)	Z value	Statistical model (method)
Short vs. Long implants	22	2.28 (1.46, 3.57)	0.0003	0	3.61	Fixed effects
Titanium modified fluoride treated nanostructured surfaces [14,19,23,28,29,33,34]	7	3.54 (1.00, 12.52)	0.05	0	1.96	Fixed effects
Novel nanostructured calcium-incorporated surface [13,17,20,25,31]	5	1.38 (0.63, 3.01)	0.42	0	0.81	Fixed effects
Hydrophilic sandblasted acid-etched [18,21,22,26,32]	5	3.00 (1.20, 7.48)	0.02	0	2.35	Fixed effects
Conventional sandblasted acid-etched [15,27,30]	3	3.56 (0.77, 16.48)	0.10	0	1.62	Fixed effects
Dual-acid-etched surface coated with nanometer scale crystals of calcium phosphate [24,31]	2	2.01 (0.72, 5.61)	0.18	0	1.34	Fixed effects

P value (≤0.05): statistically significant.
RR: risk ratio, CI: confidence interval.

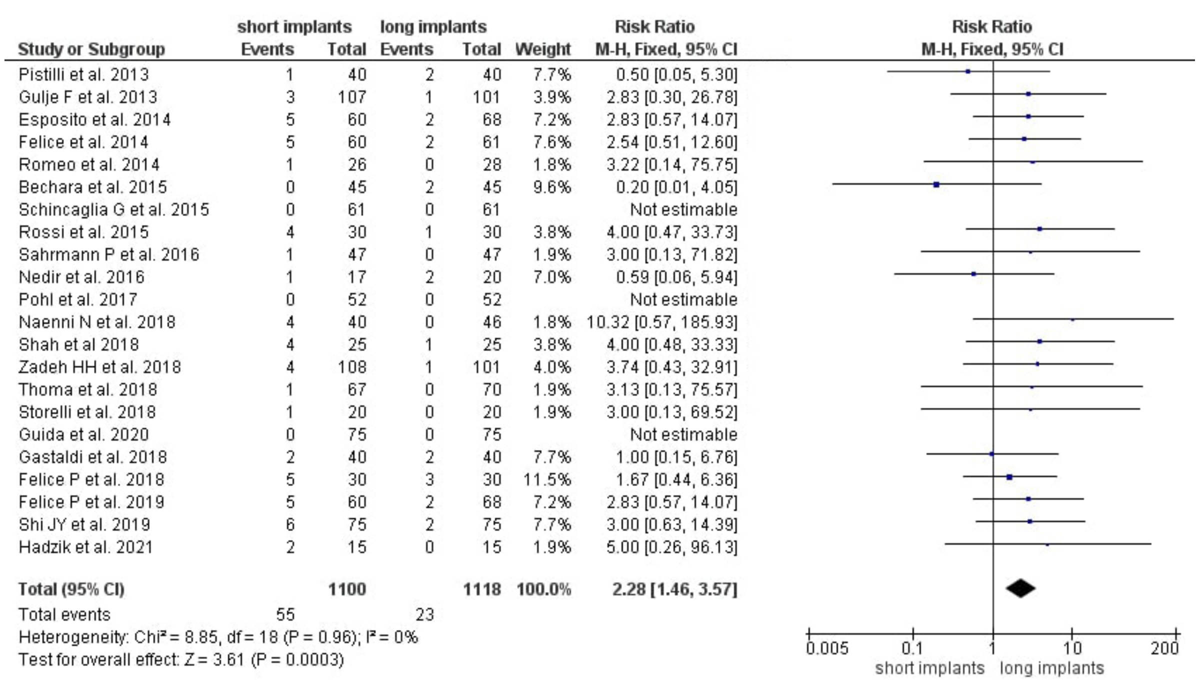

Figure 3. Forest plot of the overall survival rate analysis of short and long implants irrespective of surface.
RR: risk ratio, CI: confidence interval.

Study or Subgroup	short implants Events	short implants Total	long implants Events	long implants Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Rossi et al. 2015	4	30	1	30	17.2%	4.00 [0.47, 33.73]
Sahrmann P et al. 2016	1	47	0	47	8.6%	3.00 [0.13, 71.82]
Nedir et al. 2016	1	17	2	20	31.7%	0.59 [0.06, 5.94]
Naenni N et al. 2018	4	40	0	46	8.0%	10.32 [0.57, 185.93]
Shi JY et al. 2019	6	75	2	75	34.5%	3.00 [0.63, 14.39]
Total (95% CI)		**209**		**218**	**100.0%**	**3.00 [1.20, 7.48]**
Total events	16		5			

Heterogeneity: Chi² = 2.68, df = 4 (P = 0.61); I² = 0%
Test for overall effect: Z = 2.35 (P = 0.02)

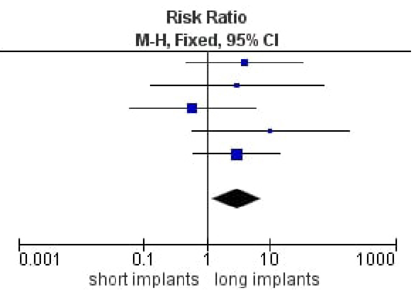

Figure 4. Forest plot of the survival rate analysis of short and long implants with hydrophilic sandblasted acid-etched topography.
RR: risk ratio, CI: confidence interval.

Study or Subgroup	Short implants Events	Short implants Total	Long implants Events	Long implants Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Gulje F et al. 2013	3	107	1	101	33.7%	2.83 [0.30, 26.78]
Schincaglia G et al. 2015	0	61	0	61		Not estimable
Pohl et al. 2017	0	52	0	52		Not estimable
Thoma et al. 2018	1	67	0	70	16.0%	3.13 [0.13, 75.57]
Zadeh HH et al. 2018	4	108	1	101	33.9%	3.74 [0.43, 32.91]
Guida et al. 2020	0	75	0	75		Not estimable
Hadzik et al. 2021	2	15	0	15	16.4%	5.00 [0.26, 96.13]
Total (95% CI)		**485**		**475**	**100.0%**	**3.54 [1.00, 12.52]**
Total events	10		2			

Heterogeneity: Chi² = 0.10, df = 3 (P = 0.99); I² = 0%
Test for overall effect: Z = 1.96 (P = 0.05)

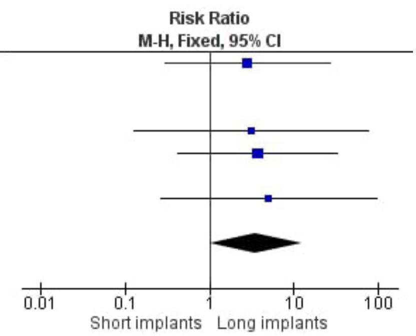

Figure 5. Forest plot of the survival rate analysis of short and long implants with fluoride-modified titanium oxide surfaces.
RR: risk ratio, CI: confidence interval.

oxide fluoride-modified short implants failed 3 and 3.54 times more frequently, respectively, than correspondingly surface-modified long implants. The survival rates of implants with nanostructured calcium phosphate-modified surfaces (P=0.42; RR=1.38; 95% CI, 0.63, 3.01), conventional sandblasted acid-etched surfaces (P=0.10; RR=3.56; 95% CI, 0.77, 16.48), and dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals (P=0.18; RR=2.07; 95% CI, 0.72, 5.61) were statistically insignificant between short and long implants (**Figures 6-8**). The wide CIs also indicate the uncertain impacts of the surface changes, which are due to the limited number of studies involving each surface. The absolute effect of the failure rate of all short implants irrespective of surface was 2.1% greater than that of the long implants (**Supplementary Table 1**).

Study or Subgroup	short implants Events	short implants Total	long implants Events	long implants Total	Weight	Risk Ratio M-H, Fixed, 95% CI
Pistilli et al. 2013	1	40	2	40	19.5%	0.50 [0.05, 5.30]
Esposito et al. 2014	5	60	2	68	18.3%	2.83 [0.57, 14.07]
Bechara et al. 2015	0	45	2	45	24.4%	0.20 [0.01, 4.05]
Gastaldi et al. 2018	2	40	2	40	19.5%	1.00 [0.15, 6.76]
Felice P et al. 2019	5	60	2	68	18.3%	2.83 [0.57, 14.07]
Total (95% CI)		**245**		**261**	**100.0%**	**1.38 [0.63, 3.01]**
Total events	13		10			

Heterogeneity: Chi² = 3.95, df = 4 (P = 0.41); I² = 0%
Test for overall effect: Z = 0.81 (P = 0.42)

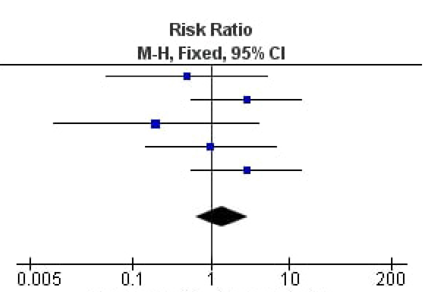

Figure 6. Forest plot of the survival rate analysis of nanostructured calcium phosphate-modified short and long implants.
RR: risk ratio, CI: confidence interval.

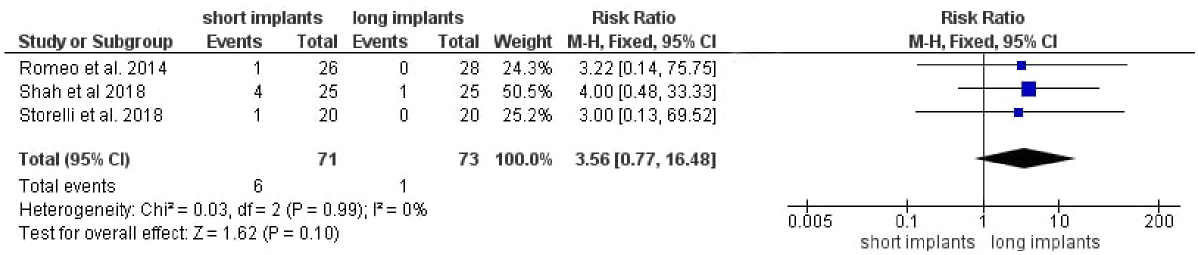

Figure 7. Forest plot of the survival rate analysis of conventional sandblasted and acid-etched short and long implant surfaces.
RR: risk ratio, CI: confidence interval.

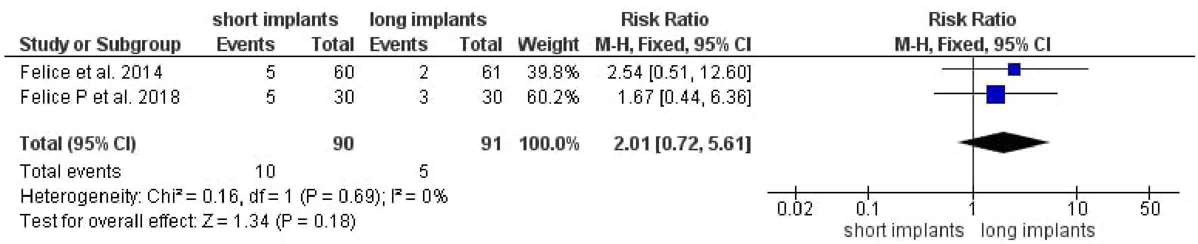

Figure 8. Forest plot of the survival rate analysis of short and long implants with dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals.
RR: risk ratio, CI: confidence interval.

Marginal bone loss

Seventeen studies [13-34] assessed the differences in MBL around the implants using mean values (mm), and only the final follow-up data of the studies were used (**Table 5**). In all of these studies, the MBL was calculated as the linear measurement from the coronal margin of the implant shoulder to the most coronal point of bone-to-implant contact. The overall analysis showed a highly significant difference between short and standard implants (P<0.0001; MD, −0.43; 95% CI, −0.63, −0.23) with I^2=97% (**Figure 9**). Overall, the marginal bone loss was smaller among the short implants. A statistically significant difference was observed with nanostructured calcium phosphate-modified surface implants (P=0.05; MD=−0.23; 95% CI, −0.45, −0.00); however, the results should be taken with caution, as the heterogeneity (I^2) observed was 94% (**Figure 10**). The differences in MBL between short and long implants was statistically insignificant for titanium oxide fluoride-modified (P=0.61; MD=−0.04; 95% CI, −0.21, 0.12) and conventional sandblasted acid-etched implants (P=0.86; MD=0.03; 95% CI, −0.28, 0.34) (**Figures 11** and **12**). However, the assessment of the hydrophilic sandblasted acid-etched surface (P=0.02; MD=−0.23; 95% CI, −0.42, −0.04) and the dual acid-etched surface coated with nanometer-scale calcium phosphate crystals

Table 5. Summary of meta-analyses comparing marginal bone level of different surface modified short vs. conventional implants

Implant surface	Studies	Pooled MD (95% CI)	*P* value	I^2 value (%)	Z value	Statistical model (method)
Short vs. Long implants [13-18,20-25,27,28,31,33,34]	17	−0.43 (−0.63, −0.23)	<0.0001	97	4.20	Random effects
Titanium modified fluoride treated nanostructured surfaces [14,23,28,33,34]	5	−0.04 (−0.21, 0.12)	0.61	82	0.51	Random effects
Novel nanostructured calcium-incorporated surface [13,17,20,25,31]	5	−0.23 (−0.45, −0.00)	0.05	94	1.98	Random effects
Hydrophilic sandblasted acid-etched [18,21,22]	3	−0.23 (−0.42, −0.04)	0.02	0	2.42	Fixed effects
Conventional sandblasted acid-etched [15,28]	2	0.03 (−0.28, 0.34)	0.86	0	0.17	Fixed effects
Dual-acid-etched surface coated with nanometer scale crystals of calcium phosphate [24,31]	2	−0.78 (−0.96, −0.59)	<0.0001	0	8.28	Fixed effects

P value (≤0.05): statistically significant.
MD: mean difference, CI: confidence interval.

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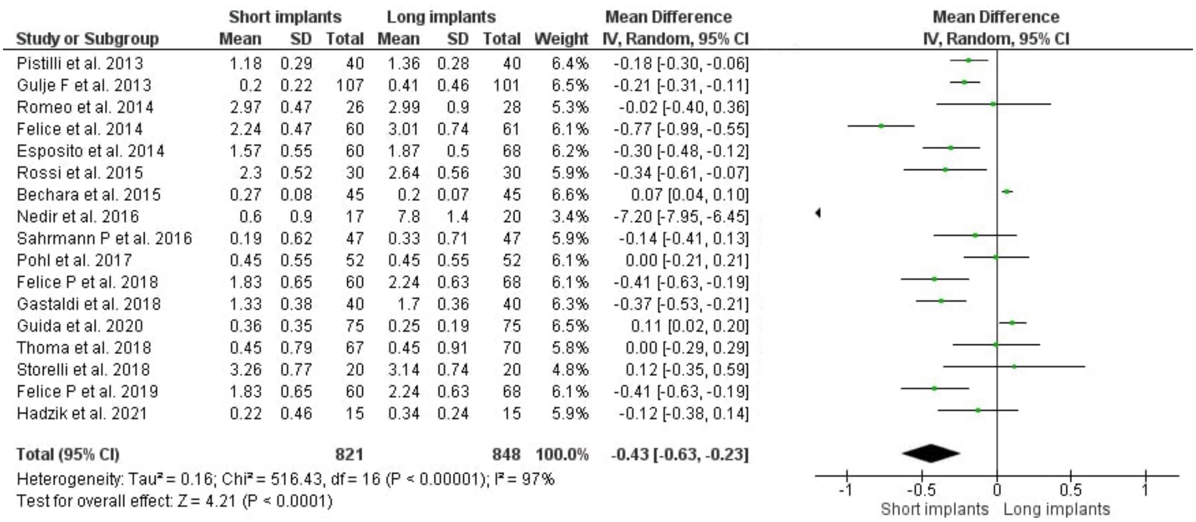

Figure 9. Forest plot of the marginal bone level analysis of all short and long implants irrespective of surface.
SD: standard deviation, MD: mean difference, CI: confidence interval.

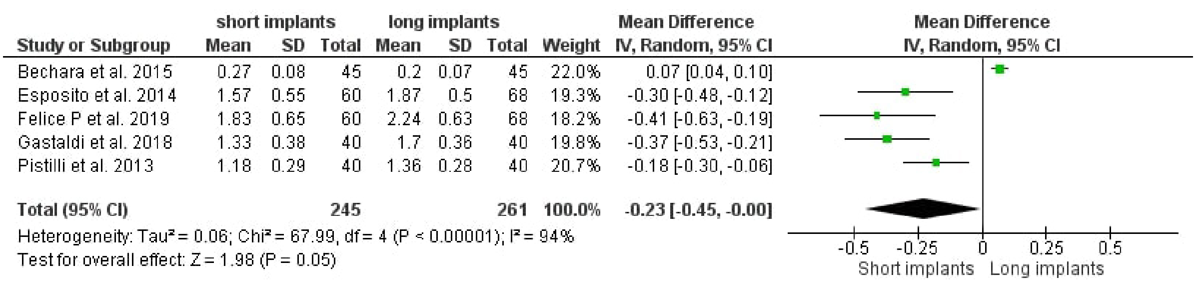

Figure 10. Forest plot of the marginal bone level analysis of nanostructured calcium-incorporated short and long implants.
SD: standard deviation, MD: mean difference, CI: confidence interval.

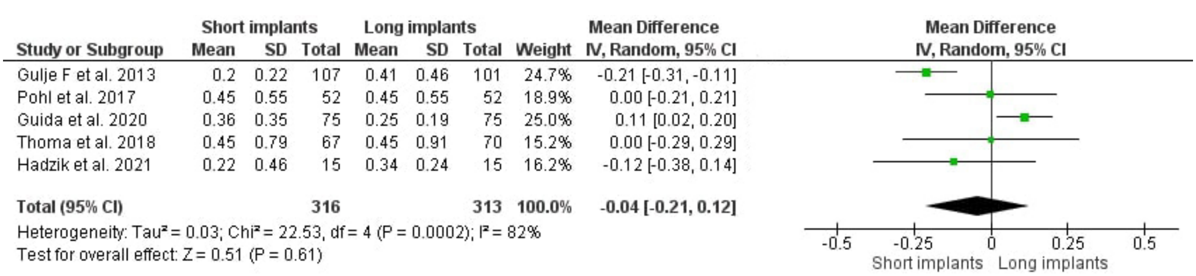

Figure 11. Forest plot of the implant survival rate and subgroup analysis of short and long implants with fluoride-treated nanostructured surfaces.
SD: standard deviation, MD: mean difference, CI: confidence interval.

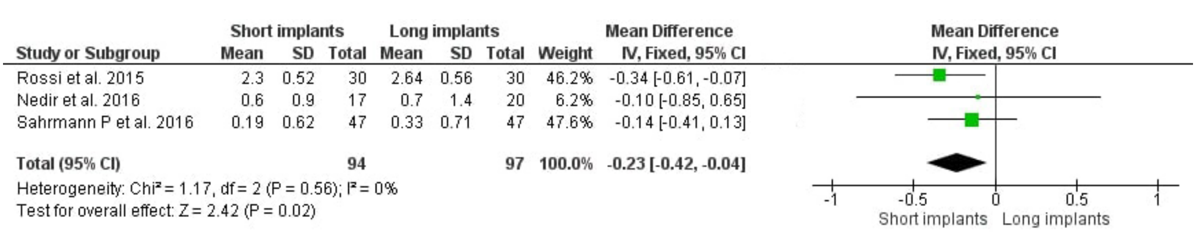

Figure 12. Forest plot of the marginal bone loss analysis of short and long implants with hydrophilic sandblasted acid-etched surface topography.
SD: standard deviation, MD: mean difference, CI: confidence interval.

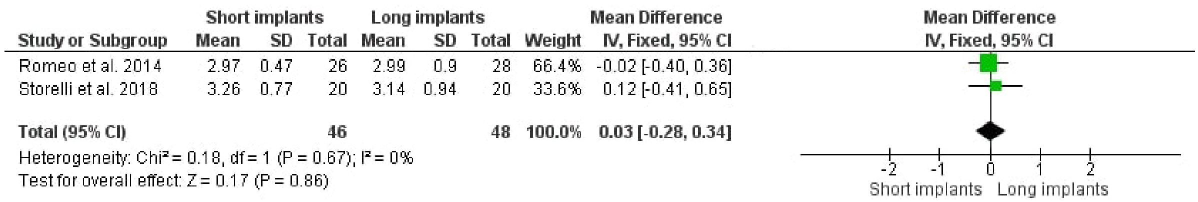

Figure 13. Forest plot of the marginal bone loss analysis of short and long implants with sandblasted large-grit acid-etched surfaces.
SD: standard deviation, MD: mean difference, CI: confidence interval.

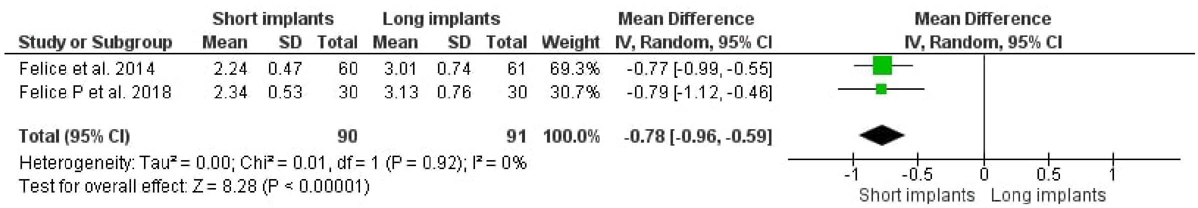

Figure 14. Forest plot of the marginal bone loss analysis of short and long implants with dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals.
SD: standard deviation, MD: mean difference, CI: confidence interval.

($P<0.0001$; MD=−0.78; 95% CI, −0.96, −0.59) revealed statistically significant differences between short and long implants (**Figures 13** and **14**).

Complications

Mechanical

Fifteen studies assessed mechanical complications, such as abutment fracture, prosthesis and screw loosening, crown failure, minor chipping and screw loosening, and prosthesis decementation [11,14-17,21,25,27,30-35,37] (**Table 6**).

Table 6. Data of the implant complications

Study	Mechanical	Biological	Complications of short implants	Complications of long implants
Pistilli et al. (2013) [13]	Prosthesis failure=3 implants	Transient paraesthesia of the lip: i) 14 patients treated with augmentation ii) 8 patients treated with short implants Schneider membrane was perforated=5 patients A small intra-surgical haemorrhage=1 patient Flap dehiscence=1 patient Graft failure=1 patient	8	22
Guljé et al. (2013) [14]	Abutment screws loosening=6 (3 short and 3 long implants) Healing caps loosened=4 (3 short and 1 long implant) The provisional prosthesis fracture=2 (1 in each group) The definite FPD loosening=4 (long implants)	-	7	9
Romeo et al. (2014) [15]	Prosthesis decementation=5 (3 short implant and 2 long implants) Chipping=2 (1 in each group)	Mucositis=1 (short implant group)	5	3
Felice et al. (2014) [16]	Prosthesis failure=10 (5 implants in each group) Abutment screw loosening=2 patients (short implants group) Ceramic fracture=1 patient (long implant group) Prosthesis fracture=1 patient (short implant group)	Augmentation failure=2 Transient paraesthesia=16 Dehiscence=1	6	25

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https://doi.org/10.5051/jpis.2007340367

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Table 6. (Continued) Data of the implant complications

Study	Mechanical	Biological	Complications of short implants	Complications of long implants
Esposito et al. (2014) [17]	3 abutments loosening	Post-augmentation paraesthesia Sinus epithelium perforation 3 abscesses (peri-implantitis) Peri-implant mucositis	12	13
Rossi et al. (2016) [18]	-	Fracturing of surrounding bone around short implants	Not mentioned	Not mentioned
Schincaglia et al. (2015) [19]	Not mentioned	Not mentioned	Not mentioned	Not mentioned
Bechara et al. (2017) [20]	No mechanical complications	Intraoperative & immediately postoperative: 3 were (intraoperative bleeding) and 16 were (1 patient experienced pain and swelling after surgery, and 14 patients experienced swelling alone) Late postoperative complication: one patient experienced a (chronic sinus infection with complete graft loss) which led to the loss of 2 implants	0	19
Nedir et al. (2017) [21]	-	mBI, probing depth	1	3
Sahrmann et al. (2016) [22]	Loosening of abutment screw=3	Bleeding on probing=62 (30 short and 32 long implants) Probing depth >5 mm=5 (short implants) Recession=2 short implants and 1 long implant	Not mentioned	Not mentioned
Pohl et al. (2017) [23]	Loosening or a fracture of the abutment screw=10	-	Not mentioned	Not mentioned
Felice et al. (2018) [24]	Crown failure	Intra-surgical haemorrhage and mandibular graft failure Transient paraesthesia of the lip Membrane perforation	8 patients (prosthetic=1 implants)	14 patients
Gastaldi et al. (2018) [25]	Prosthetic screw loosening	Intra-surgical haemorrhage Fracture of the osteotomised mandibular graft plate Maxillary sinus perforation	1 patients (2)	2 patients (2)
Naenni et al. (2018) [26]	Minor chipping and screw loosening	-	Not mentioned	Not mentioned
Shah et al. (2018) [30]	-	-	-	-
Storelli et al. (2018) [27]	Decementation (n=2) Chipping (n=6)	Mucositis (n=5)	15 implants (9 patients)	13 implants (13 patients)
Thoma et al. (2018) [28]	Fracture of abutment screw, screw loosening, chipping of veneering ceramic, lost crown and loss of retention (decementation of crown)	-	21	14
Zadeh et al. (2018) [29]	Abutment fracture, Prosthesis and screw loosening	-	Abutment fracture=5 Prosthesis and/or screw loosening=3	Abutment fracture=2 Prosthesis and/or screw loosening=7
Felice et al. (2019) [31]	Prosthesis decementation	Sinus membrane perforation Paraesthesia Abscess around implants	16	12
Shi et al. (2019) [32]	Not mentioned	Sinus membrane perforation	7	6
Guida et al. (2020) [33]	Fracture of the acrylic veneer=3 patients (short implants) Cantilever fractures=3 patients (2 long implant group and 1 in short implant)	Wound dehiscence=1 patient (long implant group) Peri-implant mucositis=2 (1 in each group)	Not mentioned	Not mentioned
Hadzik et al. (2021) [34]	Chipping of the ceramic Decementation of the crown Abutment screw loosening without the decementation of the crown 40% short implants 60% long implants	-	Not mentioned	Not mentioned

-: no data available.

Biological

Seventeen studies reported biological complications, such as sinus membrane perforation, abscess formation, peri-implantitis, paresthesia, nasal bleeding and headache, fracturing of the bone surrounding short implants, intraoperative hemorrhage, and mandibular graft failure [11,15-18,20-24,29,32,36] (**Table 6**).

DISCUSSION

To our knowledge, this is the first meta-analysis to compare the survival rate and MBL between surface-treated short (≤8 mm) and long (>8 mm) implants.

No consensus yet exists in the literature regarding the definition of short implants. In recent studies, implants of ≤8 mm were defined as short and implants of >8 mm as long or standard [40,41]. Other researchers insist that implants 8 mm and shorter should be considered short and implants 6 mm and shorter extra-short implants [42]. Overall, the recent literature indicates that short implants have a length equal to or less than 8 mm. Thus, in this meta-analysis, we defined short implants as ≤8 mm and long implants as >8 mm. In all of the included studies, surviving implants were defined as implants that remained functional post-loading, while failed implants were those that were mobile and were removed from the patient. Innumerable studies and reviews have assessed the effects of implant length on the survival rate and MBL based on data from prior to 2010, so RCTs published in the last 11 years (2010–2021) were selected. All studies compared the survival rates and MBLs of surface-modified short vs. long implants with at least 1 year of follow-up.

The results of this meta-analysis indicated that surface alteration influenced the impact of implant length on the survival rate and MBL. The risks of failure of hydrophilic sandblasted acid-etched and fluoride-modified implants were 3 to 3.54 times greater in short than in long implants. Similarly, significantly reduced bone loss (−0.23 to −0.78 mm) was observed in short implants modified with novel nanostructured calcium-incorporated titanium surfaces, dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals, or hydrophilic sandblasted acid-etched surfaces.

The present study reports a survival rate of 95% for surface-modified short and 97.8% for surface-modified long implants, which is similar to systematic reviews that showed 93% and 99% survival rates for short and long implants, respectively [43,44]. However, the present study reports an additional effect or improvement of surface modification on the survival rate of short implants. Histologic studies have shown that the surface modification of implants may positively affect osseointegration, but the overall implant survival rate is also affected by various clinical confounding factors, including prosthetic loading, bone quality, and crown-to-implant ratio.

Each type of implant surface modification has a demonstrated functional role. For example, a calcium phosphate dual acid-etched surface exhibits low bacterial adherence, a fluoride-modified surface promotes short healing time and facilitates early loading, and a hydrophilic sandblasted acid-etched surface has been shown to have high surface energy [45]. The present review reports that hydrophilic sandblasted acid-etched surface topography has a positive effect on the success/survival rate of implants irrespective of length; however, nothing can be definitely concluded on the effect of hydrophilic sandblasted acid-etched surface topography modification on the survival rates of short vs. long implants [18,21,22,26,32]. The MBLs of short and long implants with hydrophilic sandblasted acid-etched surfaces were improved due to the high surface energy and improved wettability of that topography [45,46].

The reasons for the failures of short and long implants were not specified in most of the studies. However, a few studies reported the reasons for the failure of short implants as "early failures" (caused by chronic sinus infection with loss of integration/implant stability) and type IV bone quality [18]. Also, data regarding failed short and long implants over follow-up periods of 1, 5, 8, and 10 years in some studies indicated that most of the implant failures occurred in the first year of loading; no differences were present in the implant failure rate at the end of 5 or 10 years of follow-up compared to 1 year of follow-up [13-34].

The external validity of the present study regarding the MBL indicates relatively low generalizability to similar populations. The substantial heterogeneity observed in the MBL was present because most studies have reported superior MBL around short implants, and few have done so for long implants. This is a limitation of the present study. Zadeh et al. [29] reported a maximum of 1 mm of bone loss around short implants and 1–3 mm of bone loss around long implants at 3 years. The author reported that this could be due to increased generation of heat during surgery with deeper osteotomy preparation, stress shielding, or a manifestation of the more crestal position of the head of the long implant.

The majority of studies have compared the outcomes of short and long implant placement in conjunction with vertical augmentation/maxillary sinus lift procedures. These studies have demonstrated that the survival rates and MBLs associated with surface-modified short implants are comparable to those associated with longer implants placed in sites with vertical ridge or maxillary sinus augmentation. However, patients with long implants had a higher frequency of complications and graft failure, thereby affecting the overall survival rate associated with long implants. Therefore, short implants have emerged as a viable alternative with lower morbidity and a lower surgical complication rate.

When other variables that can influence osteointegration are taken into account (for instance, the selection of appropriate-diameter [wider] implants and the resting of the flared neck below the crestal bone level in implants placed in type III or IV bone), implant length is not a confounding factor for survival rate. The use of short implants with poor bone quality (type IV) has been identified in a few studies.

The present meta-analysis included studies with good study design and analysis, indicating that these RCTs have high internal and external validity, as measured by the GRADE score. However, due to the imprecision and uncertainty of the included RCTs, MBL analyses should be extrapolated with caution. When evaluating the effect of surface treatment on variations in implant length, we did not take into account the effects of smoking, implant diameter, platform switching or matching, bone quality, or mechanical or biological complications. Future studies should also compare the survival rates of surface-modified short and long implants not placed in conjugation with augmentation procedures.

In conclusions, this study describes the impact of surface modification on the survival rate and MBL in implants of different lengths. For implants with fluoride-modified and hydrophilic sandblasted acid-etched surfaces, long implants have better survival rates than

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short implants. Short implants with novel nanostructured calcium-incorporated titanium surfaces, hydrophilic sandblasted acid-etched surfaces, and dual acid-etched surfaces coated with nanometer-scale calcium phosphate crystals showed reduced marginal bone loss relative to longer implants of the same surface types. In certain cases in which extensive augmentation procedures are needed, short implants may still be an alternative to long implants, as augmentation procedures increase the risk of complications.

SUPPLEMENTARY MATERIALS

Supplementary Table 1

GRADE score of survival rate of surface modified short and long implants

Click here to view

Supplementary Table 2

GRADE score of marginal bone level of surface modified short and long implants

Click here to view

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